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Dynamic decision processes in complex, high-risk operations: The Yarnell Hill Fire, June 30, 2013

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ABSTRACT

Recreating the information flow in decision processes after serious accidents enables researchers and policy makers to identify both the threshold points at which action begins to fail and gaps in information processes that could be corrected to reduce risk in future incidents. The Yarnell Hill Fire of 30 June 2013 occurred in a rapidly changing, high-risk environment of the Arizona highlands in which the interaction among the physical terrain, wind and vegetation conditions, technical support structures, and organizational decision processes led to the collapse of the firefighting strategy and the loss of nineteen members of the Granite Mountain Interagency Hotshot Crew. Based on documentation from operational management manuals, accident reports, and agency records, simulation methods are used to retrace the information flow in this complex decision process and reveal fresh insights into the limitations of standard firefighting practices in rapidly escalating, dangerous, wildfire conditions.

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1. Introduction: Decision making in dynamic, urgent environments

Decision making in complex, urgent environments creates extraordinary challenges for public personnel when time and resources are constrained and the consequences of failure are severe. Risks are high, both for public personnel taking action and for the population whose lives and properties they seek to protect. As social systems become more interdependent with physical and technical systems, the array of possible interactions among individuals, groups, organizations, and the context in which they function increases, and the number of factors that influence potential actions and outcomes in constructive or destructive ways also increases. Consequently, response to extreme events becomes an emerging, large-scale, sociotechnical system of individuals, groups, organizations, and jurisdictions that necessarily need to coordinate their actions to mobilize coherent, effective operations in an often disrupted and dangerous environment. Many of the participating individuals and organizations may not know one another, and may not be familiar with the particular context for action, but presumably they rely on a common base of knowledge and training. Yet, as demonstrated in the Yarnell Hill Fire of June 30, 2013, with its devastating loss of the field firefighting unit, the Granite Mountain Interagency Hotshot Crew, the physical and technical demands of these events may exceed the organizational capacity of the emerging response system.

We examine the decision processes and interactions among policies, procedures, and practice in the context of the Yarnell Hill Fire of June 30, 2013 in order to identify the critical points at which the complex coordination of the interagency sociotechnical system mobilized to respond to this event failed. Further, we explore how decision processes might be improved to enable emergent, large-scale, sociotechnical systems to function in similar urgent, dynamic environments.

Decision making in fire management has been studied by many scholars (Weick, 1993; Klein, 1998; Wybo et al., 2001), each contributing perceptive insights to this extraordinarily difficult task. Our analysis focuses on interactions among different levels of decision making in the whole response system to investigate how component units lose or maintain their capacity for shared operations. The organizational task for each component of the system is to maintain both a detailed grasp of its particular functions within

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Abbreviations: ASM, Aerial Supervision Module; AZSF, Arizona State Forestry Division; BLM, Bureau of Land Management; COP, Common Operational Picture; DIVS A, Division Alpha (GM IHC Superintendent); DIVS Z, Division Alpha (BlueRidge Superintendent); SPG, Structure Protection Group; IAP, incident action plan; ICS, Incident Command System; ICT, Incident Commander Type; GM, Granite Mountain; IHC, Interagency Hotshot Crew; LCES, Look out, Communication, Escape Route, Safety Zone; OSC, Operation Section Chief; SEAT, Single Engine Air Tanker.

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the limits of supporting technologies in the overall response operations, and simultaneously, a clear vision of how its performance fits into the operation of the whole system, with peripheral awareness of the impact of its functions on related components. Such a task is cognitively demanding for individuals, subject to error in groups, but critical to the coherent performance of the whole system. We explore requirements for maintaining such dual level cognition in large, sociotechnical systems operating in response to extreme events.

Wildfire suppression represents a particularly challenging set of conditions for interagency operations. The physical conditions are demanding, with rugged terrain, hot, dry temperatures, and dynamically changing wind directions. In these conditions, technical support ordinarily used in firefighting may not be available or accessible. Consequently, field crews are dependent on shared training, clear organizational structure, and continual communications with their support staff and one another to maintain their role in operations. Scientific knowledge of the likely shifts in wind direction and interpretation of the characteristics of wildfire activity are crucial to maintaining accurate situation awareness at all operating levels of the response system. The capacity to adapt and adjust to dynamically changing conditions is fundamental to effective performance at all levels of the system, lest action by one component adversely affect performance or limit options for action by others.

Given increasing frequency of extreme events and increased cost of mobilizing large-scale, sociotechnical systems to respond to them, we present a profile of the complex interactions among components of an interagency response system, based on computational model, as a means of evaluating the design of such systems and improving their performance in extreme events.

2. A conceptual framework for system adaptation and change

Decision making under conditions of uncertainty has a long tradition in organizational theory (Simon, 1997; March, 1988, 1991; Weick, 1993, 1995). Much of this work has focused on decision making by individuals. Other work has focused on decision making among individuals as they are engaged in organizations. Weick (1993), in his classic article on the disintegration of organizational structure in the Mann-Gulch Fire of 1949, identified the concept of ‘heedful interrelating’ among members of a team as essential to maintain the coherence of coordinated action. Weick recognized the importance of maintaining continual awareness of a changing situation and its impact on other members of a team as the basis for adapting one’s own actions. This capacity, more intuitive and psychological than rule-directed or command-driven, is more reflective of organizational culture than structure. Consequently, it is learned most often in the context of operations, rather than from standard training manuals or procedures.

Klein and his associates (1993), in their work on ‘recognition-primed decision making,’ acknowledged the importance of learning from experience and noted the capacity of seasoned emergency personnel to draw on vignettes from past experience and assemble them quickly to create an innovative approach to an immediate problem. Klein (1998) expands on this concept in developing his characterization of decision making by teams of firefighters facing dynamic, urgent situations and the emergence of leadership in these groups as other members recognize the validity of an example being set in a specific context, even as the action may depart from formal rules.

The concept of ‘distributed cognition’ articulated by Edwin Hutchins (1995) acknowledges the process of creating a common base of knowledge for action from insights contributed by different members of a team with different backgrounds and disciplinary perspectives. In complex, decision making environments, this insight acknowledges the limits of any single actor or organization in understanding the full set of constraints in an operational environment. Similarly, Fligstein and McAdam (2012) delineate a theory of changing ‘fields of action,’ in which actions taken in one field change conditions or set constraints that affect actions in another, related field. The authors acknowledge the difference between ‘proximate’ or fields of immediate action and ‘distal’ or distant fields that, nonetheless, may exert a critical, indirect influence on operating conditions. The authors also note the force of emotional ties both among members of a group and their commitment to a larger goal for action.

While each of these authors contributes thoughtful insights to the problem of decision making under uncertainty, none of them addresses the larger, more complex problem of system integration in decision support for large-scale, sociotechnical systems operating at multiple levels of authority in rapidly changing, urgent environments. The intent of this study is to explore the potential of computational modeling to make explicit the particular interactions among physical conditions, technical support, organizational structure, and individual cognition to create a basis for system-wide operations in dynamic environments. We use as the basis for this study the case reports on the Yarnell Hill Fire prepared by the Arizona State Forestry Division (09.23.2013) and the Wildland Fire Associates (November, 2013). The reports followed the detailed procedures outlined by the Interagency Serious Investigation Guide (December, 2013) adopted by US federal agencies to investigate accidents that involve the loss of life and serious property loss. Parameters identified from these reports are then entered into a computational model using the AnyLogic software (AnyLogic 6, 2013) to display the profile for the necessary interconnections among the organizational units for the whole system to function effectively. This method of investigation incorporates elements of the methods proposed by Wybo et al. (2001) to provide independent characterization of actions in a system involving diverse participants, but adds to this approach the computational power that can display the changes essential to system performance at different situations. The resulting profile is a detailed presentation of essential connections among system components at different levels of operation as conditions change over time. It provides an assessment of the changing conditions in which the Yarnell Hill sociotechnical response system operated and the requirements for adaptation by the whole system to these conditions.

3. The Yarnell Hill Fire, 30 June 2013

Facts are retrieved from both accident reports (WFA, 2013 & Serious Accident Investigation, 2013) (see Map 1):

On June 28, 2013, at approximately 5:00 p.m., lightning strikes ignited several small fires in dry chaparral on a mountainous ridge west of the town of Yarnell, Arizona. The area had not experienced fire since 1966, and the fuel load in the region was dangerously high, given drought conditions and temperatures consistently over 100 °F. The fire was reported to the Arizona State Forestry Division (AZSF), which was monitoring 37 active fires burning statewide. The Yarnell Hill Fire was documented initially as only a half-acre in size, and crews were assigned for operations the next morning.

On June 29, the AZSF firefighter coordinated operations with a Bureau of Land Management (BLM) Duty Officer in monitoring the fire. Two Single Engine Air Tankers (SEATs) arrived to drop retardant on the fire. Since the fire was holding on all four sides, the Incident Commander, Team 4 (ICT4), released the Air Attack planes for duty in response to other fires burning in the state.

At 4:00 p.m., the wind increased fire activity, and the fire spread to approximately 100 acres. The ICT4 requested more resources, an Incident Management Team Type 2, and three Interagency Hotshot

Crews. By 7:24 p.m., the fire was spreading, with winds gusting to 20 mph. The Structure Protection Group 1 Supervisor (SPG1) arrived at 11:40 p.m. to plan structure protection for the town of Yarnell.

On June 30, 7:00 a.m., ICT4 and others from the previous shift met to brief the incoming personnel and the Granite Mountain Interagency Hotshot Crew (GM IHC) superintendent. They discussed the leader's intent and strategies for diverting the fire, now estimated at 300–500 acres, from reaching Yarnell. The GM IHC arrives, but do not attend the briefing. Instead, they hike up the hill to determine their attack strategy on the fire, identify trigger points for evacuation, and set their escape route.

By 3:30 p.m., the wind shifted, and fire activity escalated. A second firefighting team, Blue Ridge IHC, began to evacuate. The fire reached a trigger point and the Structure Protection Group Superintendent (SPG1) ordered an immediate evacuation of the town of Yarnell. At approximately 4:00 p.m., the Aerial Supervision Module 2 (ASM2) flying over the area heard a comment on the radio regarding a crew on its way to a safety zone. He assumed that the crew was Granite Mountain, and that it was safe.

By 4:22 p.m, the fire reached the second trigger point, and SPGI called for all firefighters to leave the area. At 4:37 p.m., a Very Large Airtanker flew over, seeking to drop retardant. There is a broken radio transmission, and the pilot does not understand that it is the Granite Mountain IHC requesting a retardant drop, as he assumed they were safe. GM IHC calls again urgently; ASM2 asks them to confirm location; GM IHC reports their escape route has been cut off and they are deploying shelters (Photo 1). At 4:42 p.m., ASM2 continues calling. There is no response from the GM IHC. The fast-moving fire had overtaken them. At 6:35 p.m., a Department of Park Service officer hiked to the deployment site and confirmed that all 19 firefighters were dead, in heat temperatures that had reached 2000°.

This abbreviated account summarizes only key points in the information flow among different agencies and operational units participating in this firefighting operation, but it illustrates critical factors that influenced the performance of the interagency system.

4. Methods and data

This analysis uses the case study materials from the Yarnell Hill Fire reports to construct a computational model of the different factors influencing decision making processes in this complex, interagency, sociotechnical system. Typically, the analysis of an extreme event such as the Yarnell Hill Fire Operations can be viewed as an interorganizational system, highly complex and including two parts:

- an identified-information component that includes available data and information, operational resources, technical and management documents, and training requirements;
- an unexpected-information component that includes uncertain behaviors, incomplete information, evidence of inadequate communication and/or lack of understanding, unexpected actions due to entropy within the system.

Current operational organizations value stability and balance of equilibrium to maintain performance, while extreme events represent conditions that are highly dynamic, unstable and volatile, challenging organizational performance. In this analysis, we compare information included in the accident reports published following the Yarnell Hill Fire of 30 June 2013 with available operational documentation about firefighters' training, incident command system organization, wildland fire management, and principles of fire suppression. To make this comparison explicit, we have used computational modeling to enlighten interactions among the key parameters of the operational system of wildfire suppression. The model process identifies the extent to which the sudden changes in the physical characteristics of the Yarnell Hill Fire interacted with the technical weaknesses, thresholds, bifurcations and sudden changes within the firefighting organizational structure, leading the socio-technical system toward a failure. The benefit of using computational model for this analysis is gaining the capacity to visualize the interaction of multiple components of the firefighting organization simultaneously, and to identify clearly the points of necessary connection and moments that are essential for effective system performance as well as the points of potential breakdown within the system.

A firefighting organization needs an operational framework to settle into an efficient structure while facing an extreme event. This operational framework has the fundamental objective to establish and maintain a "Common Operational Picture" (COP). A COP is traditionally obtained through the application of an incident action plan and the respect of four competencies throughout the management of an event. Moreover, any ICS member is obligated to adopt them. These competencies are at the heart of ICS training and enable ICS members to build a common operational framework, including standardized communication, behaviors, tasks and processes. The four competencies are defined within position task books developed by the National Wildfire Coordinating Group (NWCG). They are:

- Assume position responsibilities.
- Lead assigned personnel.
- Communicate effectively.
- Ensure completion of assigned actions to meet identified objectives.

The principle is clear. Each member of ICS owns a position task book including those four competencies. For each ICS position outlined in the task book, specific behaviors are defined. The goal of the set of behaviors is to meet position performance required on a wildfire assignment. A successful performance of all tasks and behaviors means that a trainee has been certified and has met the required competencies for that position. Inability to accomplish the tasks and behaviors assigned to a given position or to meet competencies required for that role creates a potential risk for the whole emergency organization or one of its members.

Concretely, what does this ICS training structure mean? (PMS 311, 2009) Each qualified member of an ICS structure has been certified to know how ICS works and what is expected from him or her. All ICS team members are assumed to be familiar with common responsibilities. Thus, during an incident, training anticipates that all team members recognize a Common Operational Picture to "ensure completion of assigned actions to meet identified objectives" by "assuming position responsibility and leading assigned personnel" through an "effective communication." To accomplish hazardous missions and objectives in a safe manner, all ICS members have completed the same training and have been certified as qualified to respond to complex situations in rapidly changing and high-risk environments.

This analysis models the structural framework of a firefighting organization operating in the dynamic, urgent environment of an unpredictable wildfire in order to understand the behavior of this complex, sociotechnical system. The use of a system dynamics approach and the study of the published accident reports focus on a particular threshold: the 'edge of chaos,' or the transition between an innovative adaptation to changing conditions and a chaotic loss of control (Kauffman, 1993; Comfort, 1999). The coherence of a dynamic system may be analyzed in terms of the degrees of *differentiation* and *connection* (Bertuglia and Vaio, 2005) among its component parts. Differentiation means the degree of diversity or heterogeneity within the system. That is, different components of the system behave in different ways, not informed by, or mindful of, one another. Connection, in contrast, means the linkages that tie the component parts of the system to one other. These linkages indicate that the system components are not independent from one other, and that information regarding the status of one component can be used to determine the status and characteristics of other components of the system.

Differentiation may lead to disorder or to the development of entropy within the system, as the component parts lose their shared operational goal. In contrast, *connection* may lead to increasing order, or the decrease of entropy, as information is shared and the component parts of the system interact productively (Tong, 2008; Comfort et al., 2011). In complex, dynamic systems, both differentiation and connection are present, and the balance between them is continually being recalibrated in response to changing operational conditions.

This analysis models the interacting forces of differentiation and connection through identifying the actions that led to differentiation in organizational structure during the Yarnell Hill Fire operations in comparison to the principles of connection among the organizational components that are defined for establishing an ICS firefighting organization specified in the ICS task books and documentation. The results are shown through selected models developed from published reports regarding this event and are easily recognized as representing the dynamic of either differentiation or connection.

The first model, Fig. 1 below, has been developed from operational documentation and can be applied to any wildland fire, including the Yarnell Hill Fire. This first model encompasses the main factors that are likely to be present in any wildland fire and that have a significant impact on the degree of differentiation within a given system, indicating the emergence of complex interactions and instability. This model shows the increase of complexity within the system and a parallel generation of instability.

The challenge in implementing any ICS structure is to take into account the main factors that affect system performance in a given incident and to provide the key components and directives through its defined structure to build an efficient and resilient organization in a dynamic context. This task is the core function involved in creating "common operational picture." The objective is to establish a resilient "connection" among components in order to decrease instability and to increase coherence in the operations of the system. The diagrams presented in Figs. 2 and 3 show how the principles of ICS take differentiation into account through the application of core competencies and specific roles.

The second model, Fig. 2, focused on general behaviors of the operations section chief type 2 & 1 (OSC). These behaviors are characteristically based on a document, PMS 311-08 (National Wildfire Coordinating Group, 2009a,b,c,d) which defines the tasks for the position of OSC. The function of this role is to increase connections within the ICS structure to maintain order during operations. The intent of these specific behaviors is to ensure global coordination within the operating system, thereby establishing a common framework for action.

The same exercise in modeling has been done for the role of Division Alpha (DIVS A). Division Alpha was the position held by the Granite Mountain Interagency Hotshot Crew Superintendent during the Yarnell Hill Fire. The following model shows behaviors that should ideally be performed by DIVS A to provide an efficient connection among all system components and ICS integration.

However, during fast-moving event it is impossible to apply and respect all of those competencies in an ideal manner due to irreversible processes and nonlinearity within components interactions.

At a given instant, some factors influencing OSC, DIVS Z (Blue Ridge IHC Superintendent) and DIVS A behaviors and dynamics can be identified from the two models, based on operational documentation and both accident reports. In light of the organizational factors in wildland fires, these interactions have a direct influence on the degrees of differentiation and connection that emerge within the inter-organizational system and, consequently, on the global management of the firefighting operation.

The following two models show the results of decision-making processes leading the organization toward increasing differentiation in performance among its component parts and to a progressive drift into failure.

5. Discussion

In such organizations, core management structures strongly impact decision making processes. In addition, in hierarchical organizations and more specifically in command and control ICS hierarchies, inherent problems are still present. Reducing information overload throughout the organizational structure creates a challenge for making appropriate decisions during extreme events. Further, hierarchies generate repetitions from subordinates. This repetition leads to the need for commands and controls to be sent and understood through several levels of operation down a hierarchy with reports on the consequences of actions taken being condensed and reported back up the chain of command. The process generates failures in communication (Richardson, 2005). Indeed, a recurrent problem of hierarchical structure lies in the capacity of personnel to react positively and efficiently to fluctuations in the operational environment due to a lack of independent decision making. A possible remedy would be to introduce a variety of decision-making centers (Von Neumann and Morgenstern, 2004). Although hierarchies are designed to decrease the transaction of information, in practice they introduce errors, biases, missing information and inadequate decision-making. This situation can be accepted to some degree in many cases, but it worsens as organizations increase in size and scale of operations. As their scope of operations escalate, organizations are exposed to an increasing number of environmental variables, and depend more and more on quickly getting, comprehending, and responding to information (Jones et al., 1961). Using a command hierarchy is effective in extending the vertical scale of organizational operations, but not its global complexity. Consequently, hierarchies are unsuccessful in acting in highly complex tasks that require rapid comprehension and flexible adaptation.

Taking into account the 'scale' of organization and its evolution during extreme event is crucial. Missing this aspect leads any organization to confusion and a loss of sensemaking (Weick, 1993). Including scale is imperative in designing effective operations for complex environments. Scale refers to the number of levels in a system that act collectively in an exactingly synchronized manner (Bar-Yam et al., 2004).The Granite Mountain IHC was a group, a team, and it can be seen as a level of organization in which all individuals have to move in the same direction at the same time. ICS also can be seen as a scale; however ICS has a hierarchical structure and one center of decision making. A successful ICS organization should be one that exhibits sufficient flexibility at every level of action necessary to complete its required tasks as defined in the NWCG task books, but sufficient order to hold and exchange information. Thus, complexity varies with scale differently in every organizational structure, and at a given scale, an organization has a limited space of possible actions.

Ban-Yam (2004, pp. 100–101) notes that 'when forces are organized hierarchically, etc., the number of possible actions at a small scale increases, as the number of small units (e.g. fire teams) increases. The number of possible actions at a large scale increases as the number of larger units (e.g. battalions) increases. So the complexity profile roughly corresponds to the number of units at each level of command (individual, fire team, squad, company, or battalion).' However, Ban-Yam adds that 'the complexity at a certain scale doesn't depend only on the number of units operating at that scale – it also depends on how independent the individuals are within fire teams, how independent fire teams are with squads, how independent companies are within battalions. When the units at a particular level of organization are more independent, the complexity is higher at that scale, but as a result, complexity at the larger scale is lower because it is more difficult to carry out coordinated actions.' He concludes by observing 'the dependence of the complexity on scale, i.e. the complexity at the individual, fire team, squad, company, and battalion levels of organization, is the complexity profile of the entire force. A force trained and organized to apply large-scale force effectively is not well suited to acting on a smaller scale and vice versa, a force designed for complex small-scale conflicts is not well suited to large-scale conflicts.' The firefighting operational system mobilized for the Yarnell Hill Fire involved organizational units operating at different scales of action, each having received training for their particular level or scale of operation, but not across the interacting levels of operation for the entire sociotechnical system. Further, complexity increases as the multilevel system interacts with a dynamic environment in multiscale operations.

Thus, the challenge for ICS and for any member, team, group, is to adapt its structure, information-processing abilities and decision-making processes to changing conditions during extreme events. Information overload remains an obstacle to effective decision making, and organizations may use mechanisms such as lapse, interval of response, filtering and processing improper information in order to manage emerging threats (Miller, 1960). Even more critical, information biases also occur as a result of the position of a decision unit in the organization and the influence that position has upon the timing and information content that reaches decision makers. In hierarchical organizations, information must travel through an extensive filtering process before it reaches the decision unit. Downs (1967) considered that in a six-level hierarchy, there may be a 98% loss of informational content between the lowest and highest level of the organization. Moreover, individuals at lower levels of the organization may have a more specific, but limited range of interests in contrast to the holistic organizational perspectives of strategic decision makers.

Absent from the reports is any information on the decision processes of the Granite Mountain IHC. While they were operating within the context of a multi-scale organizational response system, they were constrained by the limitations of the technical communications system that did not allow the kind of interactive, continual communication with other operational units that was envisioned in their training procedures. The multi-way process of interorganizational communication anticipated in the training manuals proved unworkable in the environment of a raging firestorm that disrupted the technical capacity of the communications system on which their lives depended.

The series of models presented in Figs. 1–5 document the primary function of an ICS organizational structure to be the continual assessment, integration, and communication of information that serves as the basis for decision making in urgent, dynamic environments. This process is critical in complex, sociotechnical systems that involve multiple levels of organizational operations and many types of technical support that characterize extreme events. In such situations, information is changing rapidly on multiple fields of action simultaneously and needs to be continually verified to enable valid decisions and effective performance for the operation of the whole system. This task increases in complexity as the size, scale, and scope of the incident increases and as the number of actors and organizations involved in operations increases correspondingly.

Reviewing the abbreviated timeline of actions taken in the Yarnell Hill Fire operations against the specified requirements for integration of information for a fully operating ICS organization, we find four critical points where the complexity of the operation exceeded the organizational capacity of the firefighting system

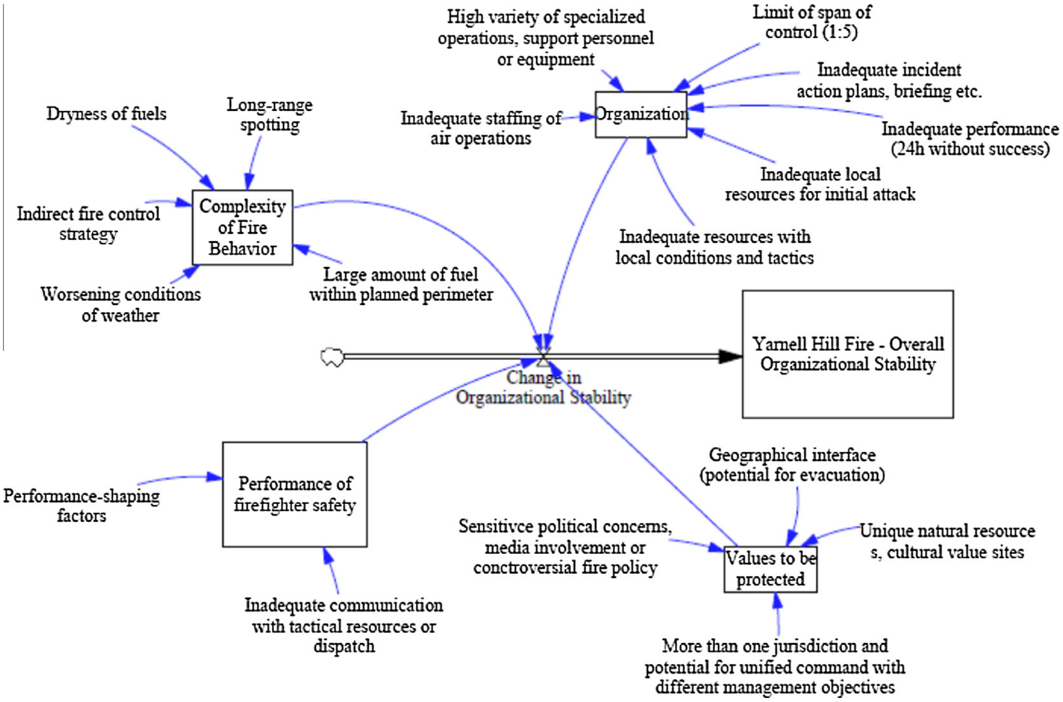

High variety of specialized operations, support personnel or equipment
Limit of span of control (1:5)
Inadequate incident action plans, briefing etc.
Dryness of fuels
Long-range spotting
Inadequate staffing of air operations
Organization
Inadequate performance (24h without success)
Inadequate local resources for initial attack
Indirect fire control strategy
Complexity of Fire Behavior
Inadequate resources with local conditions and tactics
Large amount of fuel within planned perimeter
Worsening conditions of weather
Yarnell Hill Fire - Overall Organizational Stability
Change in Organizational Stability
Geographical interface (potential for evacuation)
Performance-shaping factors
Performance of firefighter safety
Sensitivce political concerns, media involvement or concroversial fire policy
Unique natural resource s, cultural value sites
Values to be protected
Inadequate communication with tactical resources or dispatch
More than one jurisdiction and potential for unified command with different management objectives

Fig. 1. General Organizational Factors in Wildland Firefighting adapted from operational documentation. Adapted from PMS 210, 2013.

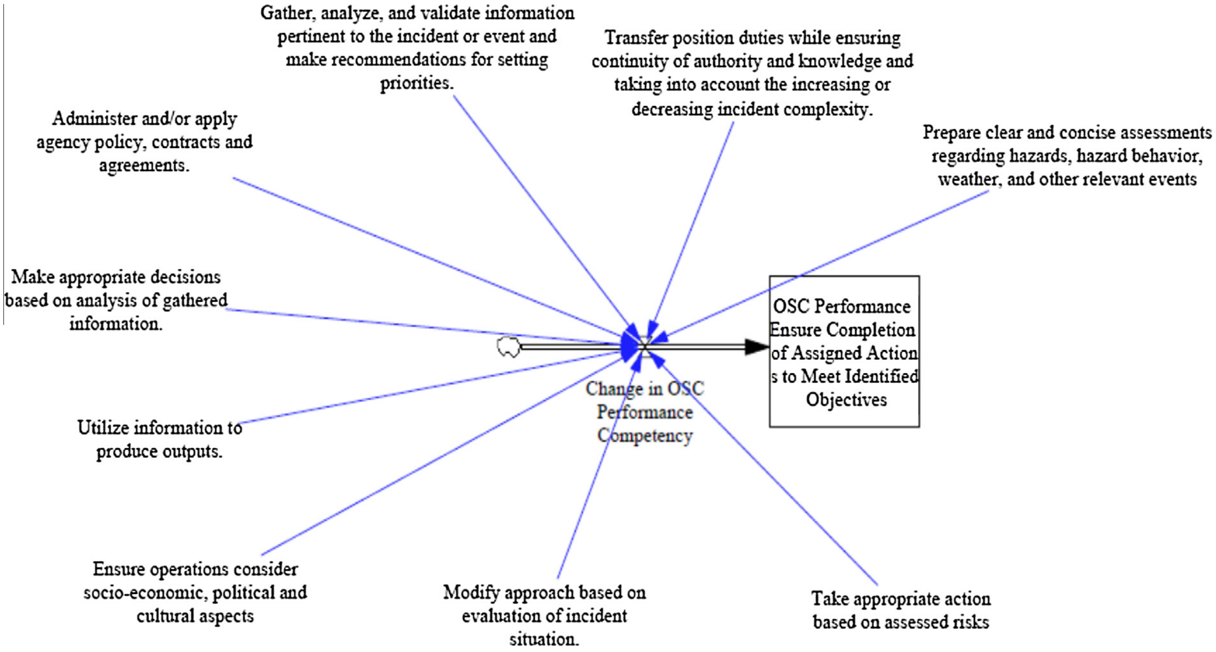

Gather, analyze, and validate information pertinent to the incident or event and make recommendations for setting priorities.
Transfer position duties while ensuring continuity of authority and knowledge and taking into account the increasing or decreasing incident complexity.
Administer and/or apply agency policy, contracts and agreements.
Prepare clear and concise assessments regarding hazards, hazard behavior, weather, and other relevant events
Make appropriate decisions based on analysis of gathered information.
OSC Performance Ensure Completion of Assigned Actions to Meet Identified Objectives
Change in OSC Performance Competency
Utilize information to produce outputs.
Ensure operations consider socio-economic, political and cultural aspects
Modify approach based on evaluation of incident situation.
Take appropriate action based on assessed risks

Fig. 2. Behaviors pertaining to OSC competency #4: Ensure completion of assigned actions to meet identified objectives. Adapted from (PMS 311-08, 2009).

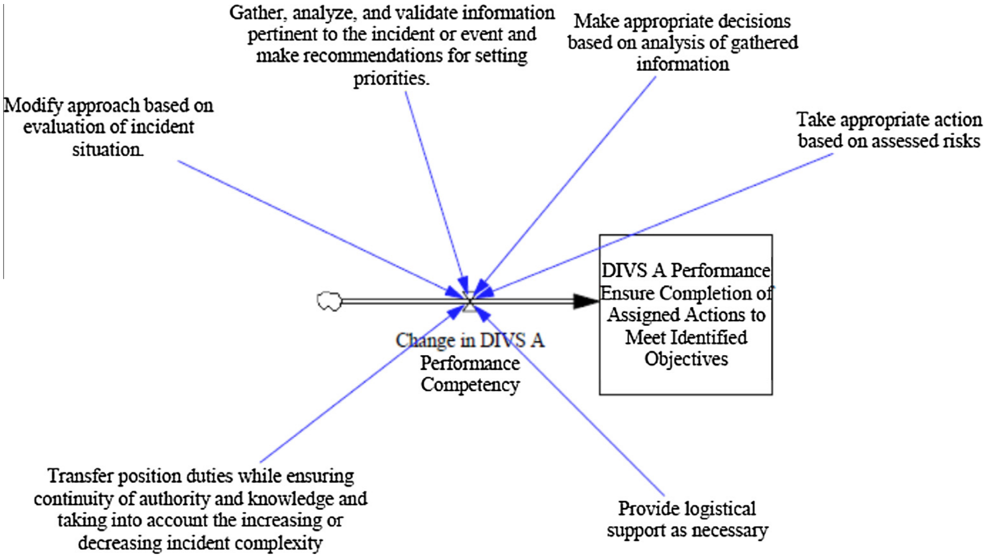

Gather, analyze, and validate information pertinent to the incident or event and make recommendations for setting priorities.
Make appropriate decisions based on analysis of gathered information
Modify approach based on evaluation of incident situation.
Take appropriate action based on assessed risks
DIVS A Performance Ensure Completion of Assigned Actions to Meet Identified Objectives
Change in DIVS A Performance Competency
Transfer position duties while ensuring continuity of authority and knowledge and taking into account the increasing or decreasing incident complexity
Provide logistical support as necessary

Fig. 3. Behaviors pertaining to DIVS A competency #4: Ensure completion of assigned actions to meet identified objectives. Adapted from (PMS 311-08, 2009).

mobilized to respond to the fire. The initial assessment of the fire in the evening of June 28 as a small incident and the limited mobilization of resources to suppress the fire on June 29 likely affected the organizational perception of the incident as relatively modest in comparison to the other 37 fires burning in Arizona on that day.

The second critical point was the 7:00 a.m. briefing on June 30 regarding the mounting fire activity and plans for attack. Although the extent of the fire and the conditions required for adequate suppression had changed significantly by the morning of June 30, only the superintendent or Operations Section Chief of the Granite Mountain Interagency Hotshot Crew participated in this briefing, not the nineteen members of the full crew. The crew members could see the conditions of fire in their immediate field of action, but could not see the distal field of action, or the whole operational context of the fire, including the extent and limits of aerial and communications support.

The third critical point was the incomplete communication at 4:00 p.m. between the ASM2 pilot flying over the area and the Granite Mountain crew on the ground. Without a specific location for the crew, the ASM2 assumed the crew was safe, although the winds were shifting suddenly and the conditions on the ground were changing dramatically. The technical communications capacity available to both pilot and ground crew proved inadequate in these rapidly changing conditions, leading the pilot to make the unverified assumption that the crew was safe.

The final critical point was at 4:37 p.m. when the pilot of a Very Large Tanker seeking to drop retardant heard a broken radio transmission from a crew on the ground requesting help, but he did not recognize the caller as the GM IHC nor could he locate the crew through the rapidly escalating fire and smoke. By 4:42 p.m., the radio went silent; the fire had overtaken the GM IHC.

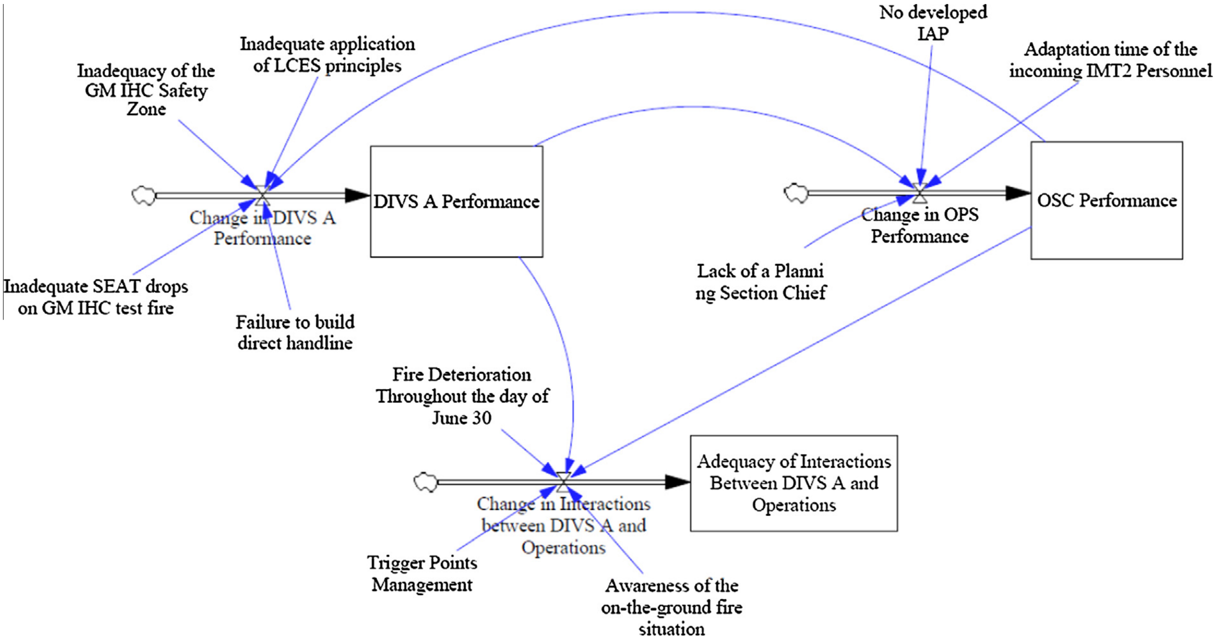

No developed IAP
Adaptation time of the incoming IMT2 Personnel
Inadequate application of LCES principles
Inadequacy of the GM IHC Safety Zone
DIVS A Performance
Change in DIVS A Performance
Change in OPS Performance
OSC Performance
Inadequate SEAT drops on GM IHC test fire
Failure to build direct handline
Lack of a Planning Section Chief
Fire Deterioration Throughout the day of June 30
Adequacy of Interactions Between DIVS A and Operations
Change in Interactions between DIVS A and Operations
Trigger Points Management
Awareness of the on-the-ground fire situation

Fig. 4. Factors influencing interactions between DIVS A and Field OSC prior to the accident Adapted from (SAT, WFA, 2013). The identified factors play a key role in providing an adequate response in case of wildland fire events. Their absence generates inappropriate responses and contributes to increased complexity and uncertainty. The factors mainly come from the Incident Command System's organization (IAP, Planning Section Chief, IMT, DIVS) or more specifically from wildland fire documentation (Firefighters Red Book, 2013) (PMS-461).

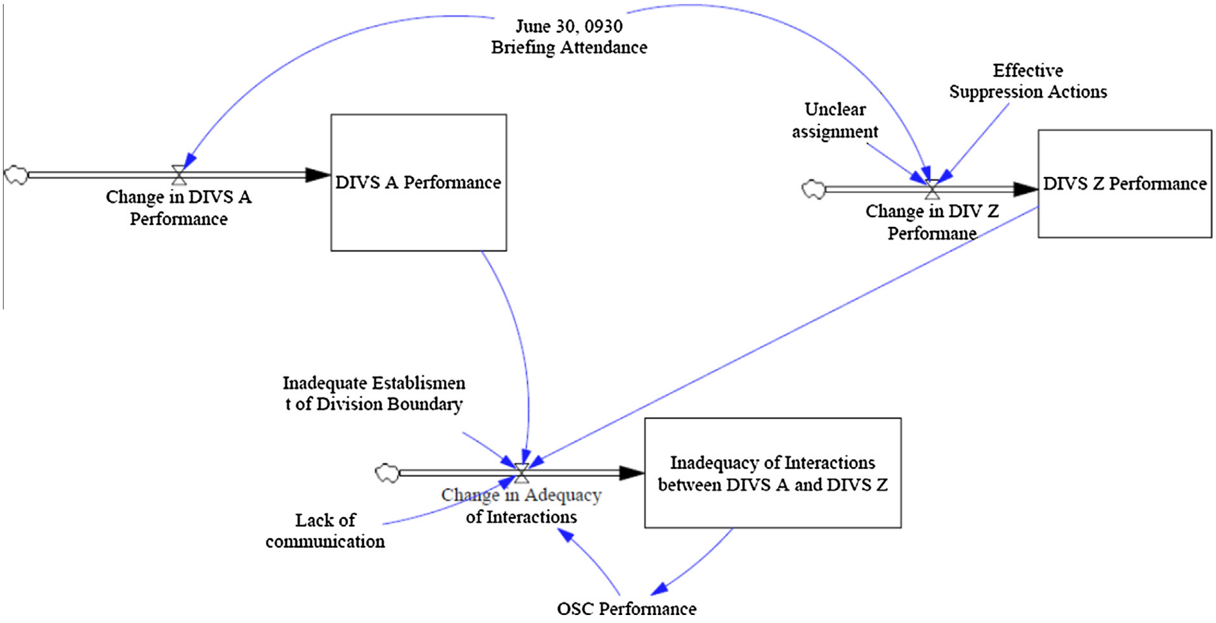
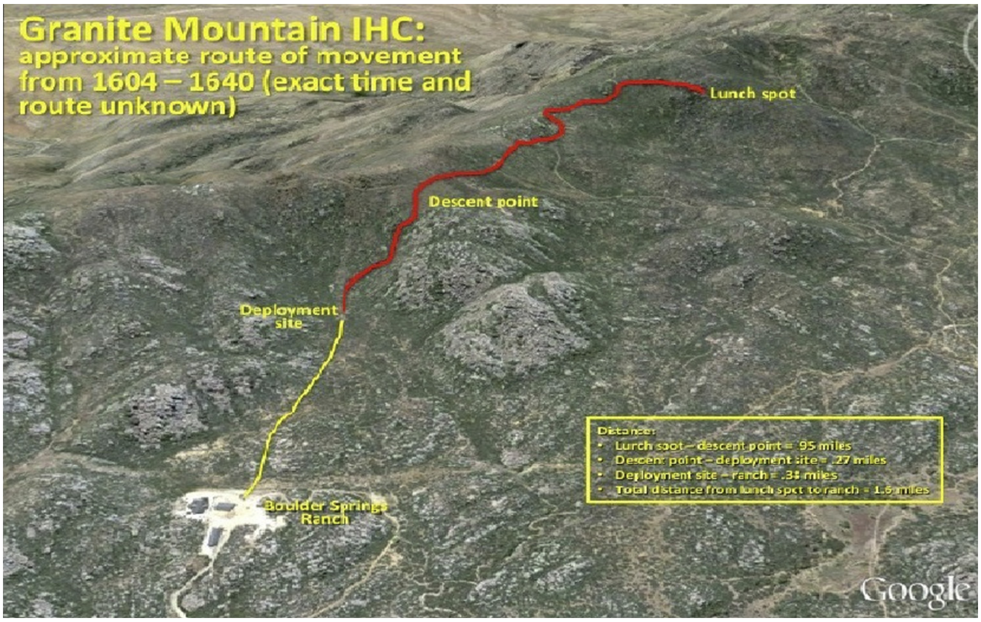

June 30, 0930 Briefing Attendance
Effective Suppression Actions
Unclear assignment
Change in DIVS A Performance
DIVS A Performance
Change in DIV Z Performane
DIVS Z Performance
Inadequate Establisment of Division Boundary
Inadequacy of Interactions between DIVS A and DIVS Z
Change in Adequacy of Interactions
Lack of communication
OSC Performance

Fig. 5. Factors influencing interactions between DIVS A and DIVS Z (Blue Ridge IHC Superintendent) prior to the accident. Adapted from (SAT, WFA, 2013). These factors are more specific to the Yarnell Hill Fire incident and show up how an inadequate management can lead to an inadequate response and, unfortunately, to losses. "After-action reports from ineffective incident responses find that response problem are far more likely to result from inadequate management than from any other single cause" (FEMA, 2013). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

At each of these four points, the ICS organization in which all participants had been trained diverged from the expected model, decreasing the connections among the ground crew, aerial supervision, and operations coordination. The deadly combination of tinder-dry fuel in a rugged, mountainous region, excessive heat, and dramatically shifting winds created the conditions for a firestorm that had not been anticipated in planning the field operations. Consequently, the actual demands for technical and organizational support to fight the Yarnell Hill Fire exceeded the capacity of the sociotechnical system mobilized to do so, resulting in the very high cost of nineteen lives. Poignantly, the connection among the crew members in the field remained strong, as the discovery of all nineteen bodies in one location indicated that they died together. The sobering question is what has been learned from the management of this incident and what can be done to avoid future losses in extreme events.


Granite Mountain IHC:
approximate route of movement
from 1604 – 1640 (exact time and
route unknown)
Lunch spot
Descent point
Deployment site
Boulder Springs Ranch
Distance:
• Lunch spot – descent point = .95 miles
• Descent point – deployment site = .27 miles
• Deployment site – ranch = .38 miles
• Total distance from lunch spot to ranch = 1.6 miles
Google

Map 1. Granite Mountain, IHC: approximate route of movement, SAT report, 2013.

Photo 1. Deployment (Entrapment) Site. Photo taken by Karim Hardy, 2014.

5.1. An integrated framework for complex decision processes

As the models in previous figures show, mobilizing interorganizational response to a dynamic, rapidly changing situation requires a continuous process of monitoring, updating, integrating, and communicating vital information to multiple operational components simultaneously. As the situation on the ground changes, actors in specific organizational roles need to adapt, both to the changing conditions on the ground and to one another.

To conclude, we recommend that extreme events' organizations develop tools to manage fast-moving incidents. We base this recommendation not only on findings from this tragic incident, but also on observations of experienced emergency managers as cited in the ICS manual: "After-action reports from ineffective incident responses find that response problems are far from more likely to result from *inadequate management* than from any other single cause (FEMA, 2013) (see Photo 2).

Photo 2. In honor of Granite Mountain IHC, Commemorative Monument at Yarnell, Az, photo taken by Karim Hardy, 2014.

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